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THESIS

INTEGRATION OF RCM ANALYSIS INTO THE S-3A MAINTENANCE PROGRAM

by

Kenneth Dean Harris

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Integration of RCM Analysis Into the S-3A Maintenance Program

by

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requirements for the degree of

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ABSTRACT

In recent years, it has been discovered that it may not be wise to do extensive preventive maintenance on a system. The system may actually tend to fail more often than if such maintenance was eliminated. The Reliability Centered Maintenance (RCM) program identifies only those preventive maintenance tasks which will provide increased reliability while, at the same time, reducing expenditures. The S-3A is a shipboard based anti-submarine warfare aircraft and was built by Lockheed Aircraft Corporation for the United States Navy. The S-3A entered service in the mid 1970's, well before the current refinements to the RCM program had been developed. As a consequence, its maintenance plan did not embody all of the changes that today's RCM program includes. A complete RCM analysis has never been performed on the S-3A aircraft because excessive amounts of resources would be required. This thesis shows where RCM can be selectively applied to the existing S-3A maintenance programs.

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LIST OF ACRONYMS

AE	Age Exploration
AMP	Analytical Maintenance Program
AARP	Aeronautical Analytical Rework Program
AMPAS	Analytical Maintenance Program Analysis Support
BUNO	Bureau Number
CM	Condition Monitoring
CFA	Cognizant Field Authority
DLM	Depot Level Maintenance
ECA	Equipment Condition Analysis
FAA	Federal Aviation Agency
FSI	Functionally Significant Item
FMEA	Failure Mode and Effects Analysis
HT	High-Time
MSG	Maintenance Steering Group
MIL-STD	Military Standard
MPA	Maintenance Plan Analysis
MIL-HDBK	Military Handbook
MSI	Maintenance Significant Item
MRC	Maintenance Requirement Card
NALC	Naval Aviation Logistic Center
NDI	Non-Distructive Inspection
NARF	Naval Air Rework Facility
NAS	Naval Air Station

NAVAIR	Naval Air Systems Command
OC	On-Condition
PM	Preventive Maintenance
RCM	Reliability Centered Maintenance
SSI	Structurally Significant Item
SDLM	Standard Depot Level Maintenance
SSP	Structural Sampling Program
WRA	Weapon Replaceable Assembly
WUC	Work Unit Code

I. INTRODUCTION

A. THE EVOLUTION OF MAINTENANCE TASK DEVELOPMENT

Early on in aviation, maintenance programs were based on the concept that periodic overhauls would increase reliability. This philosophy of trying to make the equipment like "new" to ensure operational safety continued well past World War II. However, tests conducted by the airlines in the mid 1960s suggested a new concept in preventive maintenance; that less was better. Representitives of the airlines formed a maintenance steering group (MSG) to provide guidelines for reducing the amount of preventive maintenance. The results culminated with a handbook titled, "Maintenance Evaluation and Program Development" (Ref 1). Known as MSG-1, it was in this initial stage that decision logic and procedures were first introduced for establishing a conservative preventive maintenance program. Further development of this maintenance philosophy by the Air Transport Association in 1970 lead to MSG-2 which provided a logical procedure for analyzing a piece of equipment in terms of its maintenance priority to the overall system. The final development, MSG-3, occurred when the Department of Defense contracted with United Airlines to have F. Stanley Nowlan and Howard F. Heap write a comprehensive report on what was to become known as

Reliability Centered Maintenance (RCM). The results of this effort, provided the methodology for analyzing each maintenance requirement and objectively justifing a preferred maintenance task. This program was later incorporated in MIL-HDBK-266(AS).

This evolution of MSG philosophy has provided the analyst and engineer with a logical and detailed process by which to thoroughly analyze and evaluate a maintenance program and its associated maintenance tasks.

B. OBJECTIVE

The S-3A is a shipboard based anti-submarine warfare aircraft and was built by Lockheed Aircraft Corporation for the United States Navy. The S-3A entered service in the mid 1970's, well before the RCM concept was developed. Subsequently, the S-3A maintenance plan was developed utilizing MSG-2 philosophy and did not embody the changes that RCM brought about. A complete RCM analysis has never been performed on the S-3A aircraft nor is it recommended. Excessive amounts of resources would precluded such an undertaking. But by applying RCM selectively to existing S-3A maintenance programs, cost savings can and will be realized. The logic provided by the RCM program identifies only those preventive maintenance tasks which provide increased reliability while, at the same time, reducing expenditures. The objective of this thesis is to identify

how RCM analysis could benefit the S-3A maintenance program.

It is also hoped that this thesis will provide any person not familiar with the RCM philosophy with a thorough understanding of the terminology and analytical techniques associated with RCM.

C. SCOPE

The scope of this thesis will concentrate on the S-3A aircraft and will examine only those airframe aspects of the S-3A aircraft where RCM would be most beneficial to the S-3A's maintenance program.

D. PREVIEW

Chapter II considers the major events in the development of RCM from the initial inception of MSG-1 through MSG-3. Terms and concepts associated with Reliability Centered Maintenance are also discussed. Chapter III reviews the S-3A's maintenance plan based on MSG-2 philosophy. It shows how maintenance tasks were developed. Chapter IV considers the differences between MSG-2 and MSG-3 maintenance philosophies. It also establishes how RCM can enhance the S-3A maintenance program. Chapter V presents a summary, conclusions and recommendations.

II. HISTORY OF RELIABILITY CENTERED MAINTENANCE

A. EARLY MAINTENANCE THEORY

Early pioneers in aviation operated under the assumption that if a periodic scheduled maintenance program was established it would ensure reliability and operational safety. However, by the late 50's, actual data was contradicting many of the basic assumptions of traditional maintenance practice.

Early maintenance theory was based on an intuitive belief that because mechanical parts wear out the reliability of the equipment is directly related to operating age (Ref. 2:p. 2). It followed that if one has the capability of making the equipment like "new" it would, in turn, ensure the original reliability. A problem still existed, however, in determining the interval of inspection and repair so that age limit criteria that was determined by engineering analysis would not be exceeded. It became more and more obvious that the concept of overhauling complicated equipment was of questionable benefit, both economically and from a safety and reliability standpoint (Ref 3: p. 19). Actual analysis of failure data suggested that the overhaul policies were ineffective in controlling failure rates and that failure rates actually increased after overhauls.

Our inability to predict failure rates can be partially explained by analyzing Figure 1. Also known as the "bathtub curve", it demonstrates how an aircraft that has undergone a complete overhaul could experience an initial increase in failures during the burn-in period. This trend can not be attributed to an insufficient inspection interval or overhauls that were not thoroughly performed. After this "burn in" period, the liklehood of failure remained fairly constant for most of an aircraft's useful life. It is near the end of this phase that we become concerned with determining when system wearout begins and the constant state ends.

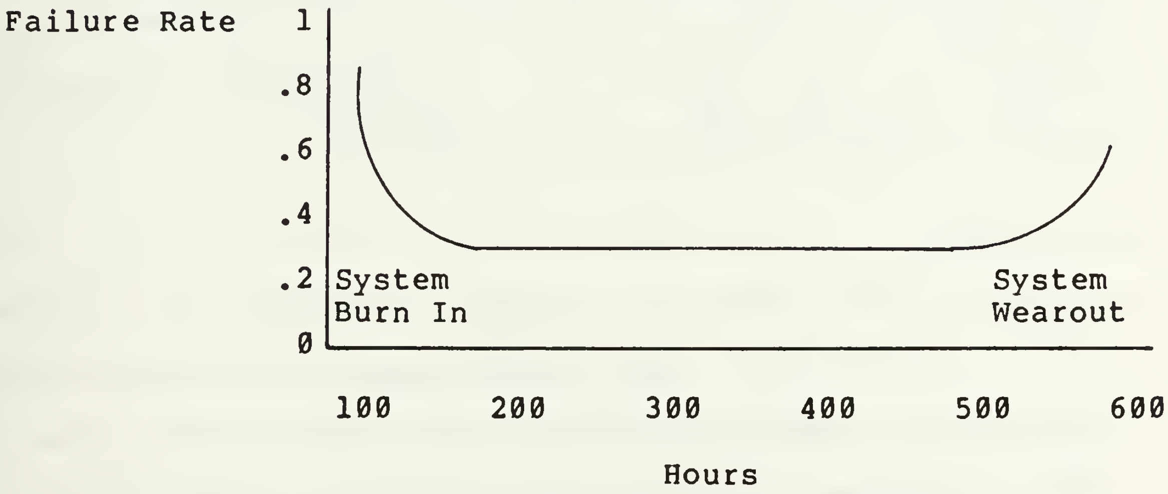

Figure 1. Failure as a Function of Flight Hours

If we concentrate on the flat part of the curve it is still possible to have high failure rates. Because of this, a task force consisting of representatives from the FAA,

airlines and aircraft manufacturers was formed to try and reduce the high rates. The work of the group led to an FAA/industry reliability program, issued November 7, 1961. The introduction to that program stated:

> The development of this program is towards the control of reliability through an analysis of the factors that affect reliability and provide a system of actions to improve low reliability levels when they exist. . . . In the past, a great deal of emphasis has been placed on the control of overhaul periods to provide a satisfactory level of reliability. After careful study, the Committee is convinced that reliability and overhaul time control are not necessarily directly associated topics; therefore, these subjects are dealt with separately.

This approach was a direct challenge to the traditional concept that the length of the interval between successive overhauls of an item was an important factor in its failure rate (Ref 2: p. 4). Up until this point, reliability was assumed if the aircraft was periodically overhauled. However, historical data proved otherwise.

B. MSG-1

Under the force of economic pressures to further reduce maintenance costs, while maintaining sufficiently high levels of reliability and safety, specialists wanted to define a generally applicable approach to the design of maintenance programs. In 1967, a joint effort, again between the FAA, airlines and aircraft manufacturers, lead to the formation of a maintenance steering group (MSG) which published a document titled <u>Handbook: Maintenance Evaluation and Program Development</u> (Ref 1). This

handbook, more commonly known as MSG-1, was used by special teams of industry and FAA personnel to develop the initial maintenance program for the Boeing 747. As described by the FAA, these teams*

> . . .sorted out the potential maintenance tasks and then evaluated them to determine which must be done for operating safety or essential hidden function protection. The remaining potential tasks were evaluated to determine whether they were economically useful. These procedures provide a systematic review of the aircraft design so that, in the absence of real experience, the best maintenance process can be utilized for each component and system.

C. MSG-2

Further development of the decision logic and procedures resulted in the 1970 publication of MSG-2,Airline/Manufacture Maintenance Program Planning Document, (Ref 4). MSG-2 logic was used to develop the maintenance program for the Lockheed L-1011, Douglas DC-10, and was first applied to Naval aircraft in 1972 on the P-3A, S-3A and F-4J. The main thrust of MSG-2 was to increase both reliability and safety while, at the same time, reducing costs associated with maintainability.

The Navy's version of MSG-2 was incorporated into a Naval Air System Command document, NAVAIR 00-25-400 (Ref 5). As stated previously, this manual was the basis by which the Navy revised the preventitive maintenance requirements of the P-3A, S-3A and F-4J. However, as the predecessor to the

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*FAA Certification Procedures, May 19, 1972 Par. 3036

RCM (Reliability Centered Maintenance) analysis, MSG-2 was utilized to develop prior-to-service programs such as the maintenance plan and phased maintenance programs. No attempt was made to incorporate historical data that could justify modification of the maintenance program after the aircraft became operational.

D. MSG-3

The Department of Defense contracted with United Air Lines, Inc. to write an extensive report on "Reliability Centered Maintenance" (RCM) in an attempt to find an approach which could incorporate actual maintenance history. Their report, (Ref 1) clarified the analysis process and provided greater detail in defining the scope and philosophy of the program.

Further refinement of the RCM concept by commercial aviation personnel lead to the development of MSG-3 (Ref 6) in 1980 and improved the analysis procedures for the aircraft structures. MIL-HDBK-266 (Ref 8) applied the MSG-3 philosophy to Naval aircraft in 1981 and has recently been superceded by MIL-STD-2173 (Ref 7) in January of 1986. The standard provides the principles of RCM and how it should be applied to all Naval aircraft, weapon systems, and support equipment. However, to date, not all Naval aircraft have had a thorough RCM analysis applied to their respective maintenance programs. The S-3A is included in this group.

E. PHILOSOPHY OF RCM

Before discussing the goals of RCM, it is important to understand the philosophy that the authors of Reference 1 presented in discussing the relationship between safety and scheduled maintenance. Their statements concerning this philosophy are summarized as follows (Ref 1: p.388):

- Failures are inevitable in complex equipment and can never be entirely prevented by scheduled maintenance.

- It is possible to design equipment so that very few of its failures or failure modes will be critical.

- Scheduled overhaul has little or no effect on the reliability of complex items. Rework tasks directed at specific failure modes can reduce the frequency of failures resulting from those failure modes, but the residual failure rate will still represent an unacceptable risk. Consequently scheduled rework is not effective protection against critical failures.

- The techniques of RCM analysis explicitly identify those scheduled tasks which are essential either to prevent critical failures or to protect against the possible consequences of a hidden failure.

- Scheduled maintenance tasks that do not relate to critical failures have no impact on operating safety. They do have an impact on operating costs, and their effectiveness must therefore be evaluated entirely in economic terms.

F. MIL-STD-2173 (AS) RCM PROCESS OVERVIEW

As now defined by DOD, RCM is a disciplined logic or methodology used to identify preventive maintenance tasks to increase inherent reliability of equipment at least expenditure of resources. MIL-STD-2173 (Ref 7) provides the procedures by which the Navy can use in applying this philoshopy to Naval aircraft. The following excerpts from

MIL-STD-2173 are intended to provide the reader with a basic understanding of the RCM analysis program. The goal of RCM is to provide the following:

a. Analyze the maintenance requirements for each type/model aircraft;

b. Objectively justify every maintenance requirement;

c. Enforce the performance of only the justified maintenance actions.

Figure 2 (Ref 9, MOD 4/6) illustrates the process of reliability centered maintenance. Although each element of the RCM process will be discussed in greater detail, a general overview of the process is warranted. Initially, each system must be categorized as either significant or non-significant. Significant items then undergo the RCM decision analysis with preventive maintenance requirements being assigned to each justifiable task. Once these requirements are determined, operating experience will either confirm or deny the maintenance task's effectiveness.

If there was no past historical data from which to base the decision logic and task selection or if a problem is identified through actual fleet experience, age exploration provides a methodology to gain additional information in determining changes to maintenance requirements. The outcome of the RCM analysis is either the redesign of the component, an adjustment in existing maintenance intervals, the identification of preventive requirements to monitor the condition, or a complete elimination of the maintenance

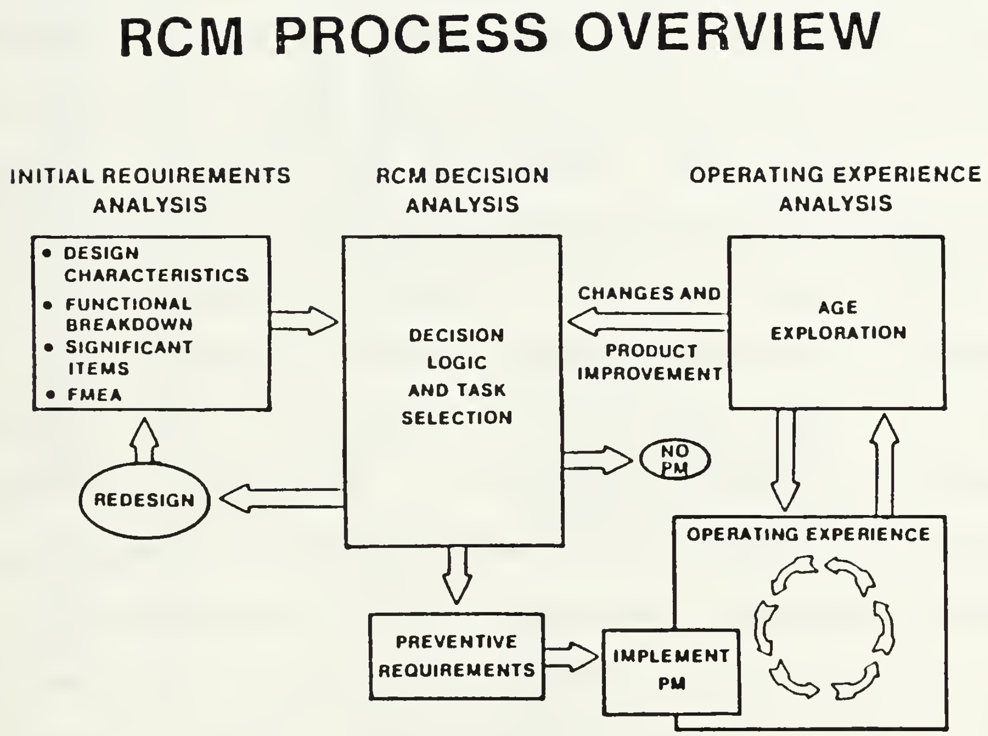

Figure 2. RCM Process Overview

task. The ultimate goal is to provide a set of fully justified maintenance tasks without wasting vital resources.

G. RCM ELEMENTS

To better understand the details of the RCM process, Figure 3 (Ref 9, MOD 4/7) identifies the major elements.

1. Significant Item Selection

The RCM process starts with the determination of the design characteristics, functional breakdown, significant item selection and Failure Mode and Effects Analysis (FMEA).

Before the analysis can begin, functional relationships between each item must be examined to determine the lowest level of item indenture. This relationship resembles a pyramid with the overall system at the apex. Figure 4 (Ref 7;pp 19) is an example of this structural breakdown by level of indenture. Functional breakdown is concerned with applying the RCM logic to the lowest level of indenture possible. Once this level is determined, an item must be classified as either significant or non-significant. There are two types of significant items, functionally significant items (FSI) and structurally significant items (SSI). A FSI is defined as an item whose loss of function would have significant consequences at the equipment level. A SSI is the specific region or element of structure whose failure would result in a major reduction in residual strength or loss of the structural function.

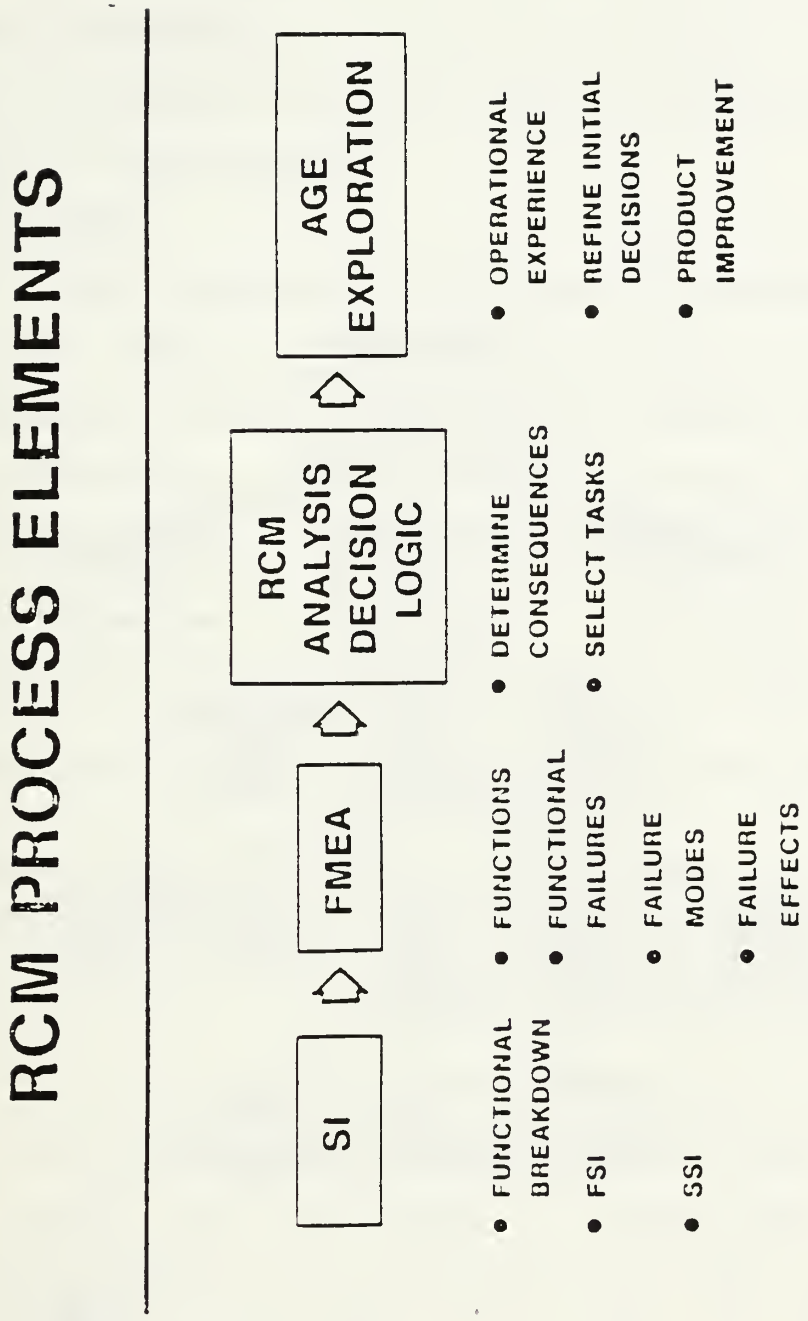

Figure 3. RCM Process Elements

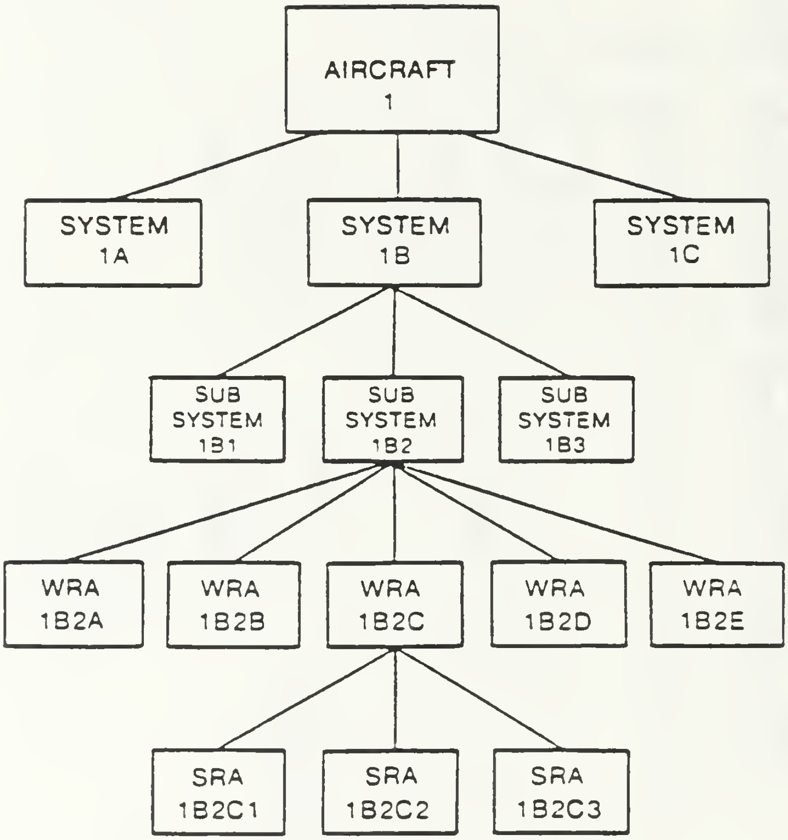

Figure 4. RCM Functional Breakdown

It is important to identify these significant items as early as possible in the acquisition cycle. Figure 5 (Ref 7, p. 18) provides a decision logic to identify an item as a FSI, SSI or non-significant.

2. FMEA

The objective of failure mode and effects analysis is to identify functions, functional failures and engineering failure modes, and the effects of failure for each significant item. An example can best describe what these terms mean. A typical hydraulic pump will be used to illustrate.

-Function: Provide hydraulic fluid at a fixed pressure and flow rate;

-Functional Failure Mode: Fails to provide hydraulic pressure;

-Engineering Failure Mode: Broken shaft;

-Failure Effects: 1.) Loss of hydraulic pump function;
2.) Loss of hydraulic system;
3.) Loss of flight control system and aircraft capability to safely fly.

It is essential to the RCM analysis process that FMEA is properly performed since it is a primary input into the overall task development. MIL-STD-1629A (Ref 10) provides guidance for documenting the FMEA analysis as an input to the RCM process.

3. RCM Analysis Decision Logic

After the item is identified as either a FSI or SSI, RCM decision logic will determine what type of consequence

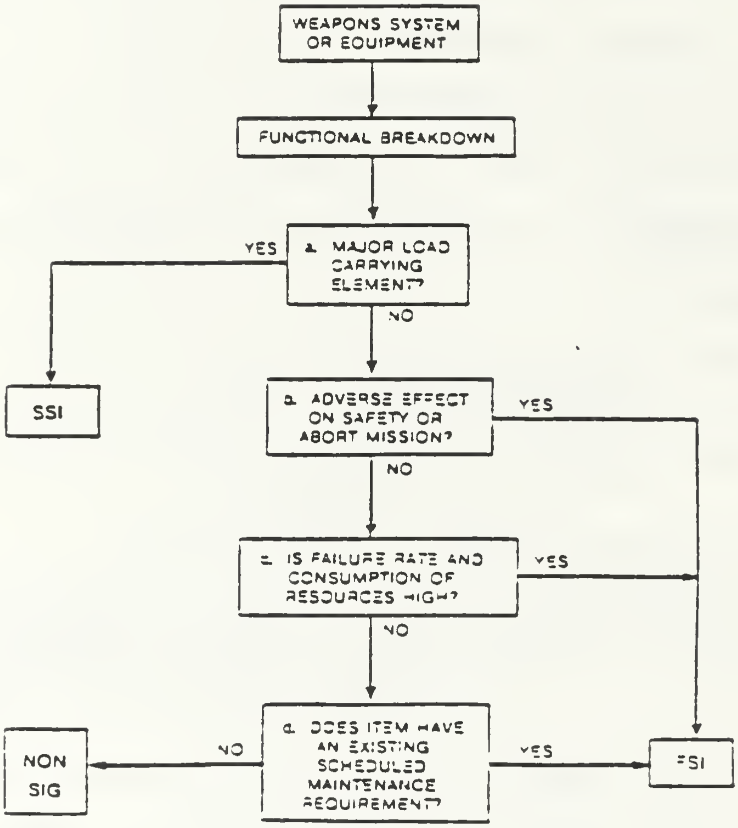

Figure 5. FSI/SSI Selection Diagram

each failure could have upon the system and what task would be most effective in preventing the failure. It is important to note the difference between effects and consequences. Failure effects are the ways in which a malfunction is characterized. The consequence is the final outcome or result of the failure effect. Figure 6 (Ref 7:p. 22) is the decision logic diagram for determining failure consequences and selecting the most appropriate maintenance task for FSI's. There are four failure consequence catagories.

a. Safety consequence;

b. Economic/Operation consequences;

c. Non-safety hidden failure consequences;

d. Safety-Hidden failure consequences.

After the failure consequences are identified, a preventive maintenance task analysis is conducted to determine that action which could best prevent the failure mode. There are five kinds of actions:

a. Servicing and lubrication;

b. On condition: Inspections of the aircraft at either the organizational, intermediate or depot level to detect failures before they can cause a functional failure;

c. Hard-time: Certain items are removed long before they are expected to fail and are either discarded or reworked;

d. Combination: Used where an "on-condition" or "hard-time" action alone proves not to be applicable or effective;

e. Failure Finding: To find hidden failures when other PM actions are not applicable or effective.

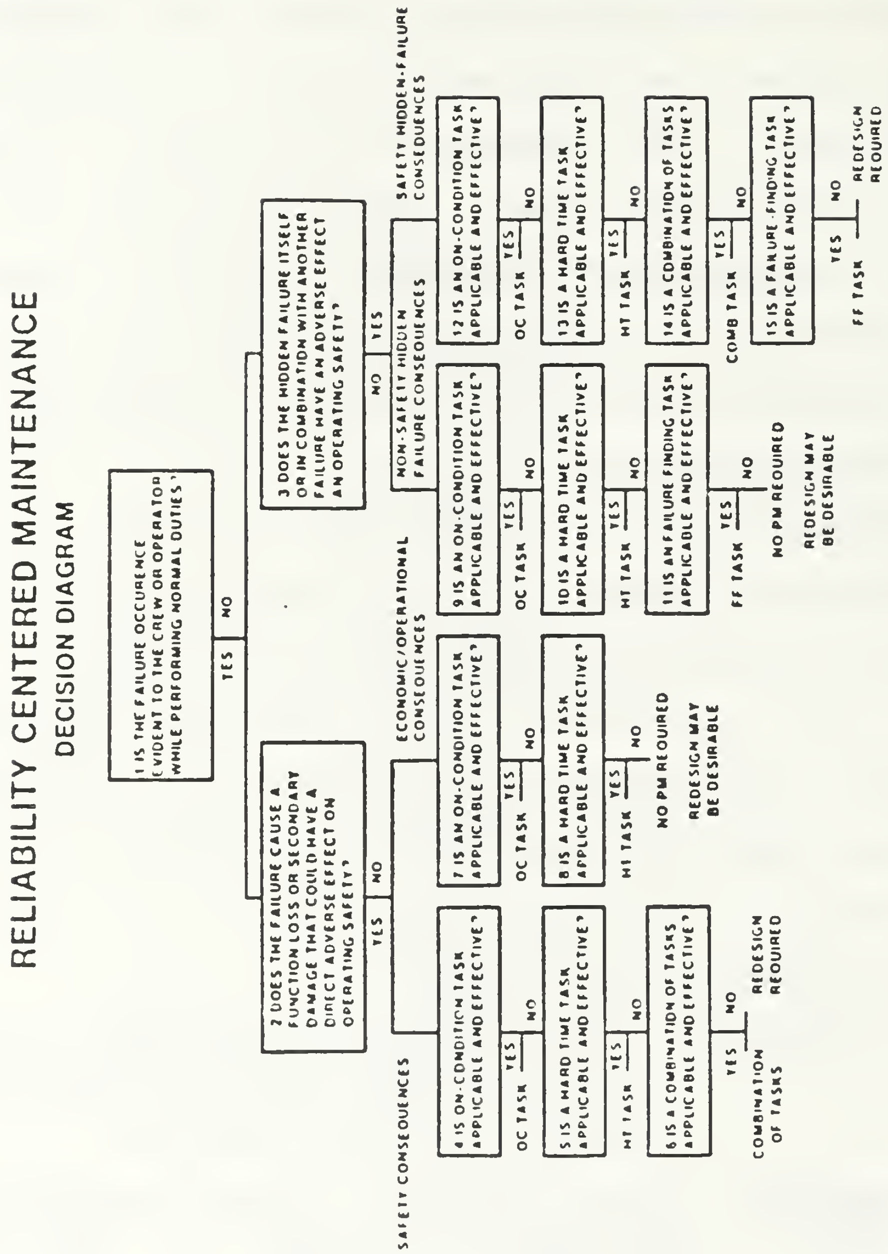

Figure 6. Decision Logic for FSI's

Figure 7 (Ref 7:p. 23) illustrates the decision logic used for SSI's. Because the failure of a structurally significant item is always safety critical, a different logic is utilized in the decision process. This logic identifies requirements based on whether the design characteristic is safe life or damage tolerant.

In the safe life structural members there are two ways to achieve the required level of safety. One is by ensuring that the member has a large margin of strength over its expected load carrying requirement. The other is by limiting the actual time before removal to a value below the expected life that was determined under laboratory stress tests.

The damage tolerant design requires that when one or more elements fail the rest of the structure must be able to carry the load. Furthermore, the rate at which a fatigue crack grows should be slow enough to allow time for its detection before a critical crack length is reached.

4. Age Exploration

Age Exploration is an intergral part of the RCM analysis process. It provides an effective means by which to further analyze those components having insufficient data from which to base a decision. Under most circumstances, the logic diagrams for the FSI and SSI selection provide a clear path to follow. However, during the RCM analysis, some logic decisions have to be made without enough data to

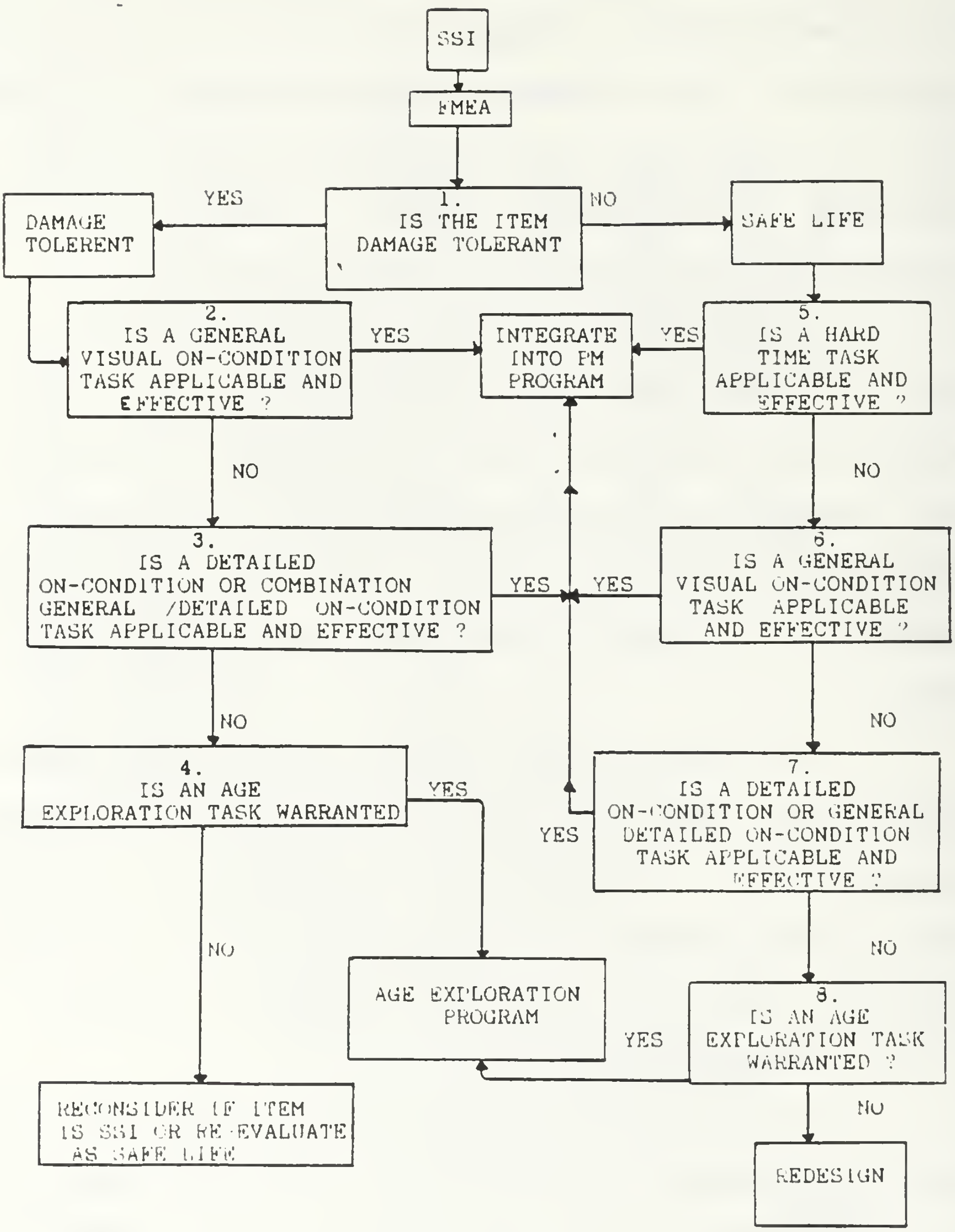

Figure 7. Decision Diagram for SSI'S

substantuate the conclusion. When a "yes" or "no" answer can not be easily given, a default logic chart, Figure 8 (Ref 7:p. 24), is used to clarify and provide guidance in selecting the proper course of action. Whenever default logic is utilized, the age exploration program described in NAVAIR 00-25-403 (Ref 11) is useful for determining if an item should be classified as significant.

Age exploration provides a methodology for gathering data that is needed to refine and revise initial maintenance tasks once an aircraft becomes operational. If age exploration is not utilized effectively, excessive maintenance costs could mount from inspections that are not warranted. An age exploration program requires the following steps:

a. Select candidates for AE by the RCM decision logic;

b. Collection of required data from tasks;

c. Conduct data analysis and obtain results;

d. Apply analysis results to PM task.

Age exploration involves specifying the actual criterion to be evaluated and the intervals for the sampling inspection. Careful consideration must be given, however, to ensure that the potential benefits of age exploration outweigh the costs of performing such an investigation.

DECISION QUESTION	DEFAULT ANSWER IF UNCERTAIN	POSSIBLE ADVERSE EFFECTS OF DEFAULT
<u>SIGNIFICANT ITEM IDENTIFICATION</u>		
Is the item significant?	Yes; Classify item as significant	Unnecessary analysis
<u>FAILURE CONSEQUENCE EVALUATION</u>		
RCM Question 1	No; Classify failure as hidden	Unnecessary maintenance or redesign
RCM Question 2	Yes; Classify item as safety critical	Unnecessary redesign or maintenance that is not cost effective
RCM Question 3	Yes; Classify item as safety hidden failure	Unnecessary redesign or maintenance that is not cost effective
<u>EVALUATION OF PROPOSED TASKS</u>		
Is a servicing or lubrication task applicable and effective?	Yes; Include task at default interval	Unnecessary maintenance
Is an OC task applicable and effective?	Yes; Use short enough intervals to make task effective	Maintenance that is not cost effective
Is HT task applicable and effective?	No; (Yes if have real and applicable data or safe life items)	Delay in exploiting opportunity to reduce costs
Is a combination of tasks applicable and effective?	Yes; Include an OC task with a HT task	Maintenance that is not cost effective

Figure 8. Default Diagram Logic Chart

H. SUMMARY

MSG-1 was originally developed so that the designer would be aware of the life cycle costs associated with maintenance and failure consequences. By being made aware of these downstream cost implications, the designer could make changes in the design characteristics in the early stages when changes are easiest and inexpensive. MSG-2 helped increase reliability and safety while reducing costs associated with maintainability. Both MSG-1 and MSG-2 provided a realistic approach in determining the tradeoffs between the safety and economic impacts of design alternatives.

MSG-3 provided the Reliability Centered Maintenance concept which further refined the approach of MSG-2 and added greatly improved analysis procedures. It also established guidance for determining those maintenance tasks that would realize the best improvement in reliability at least expenditure of resources.

The next chapter will discuss the logic of MSG-2 and how it was applied to the S-3 aircraft in determining the maintenance requirements and inspection interval formulation.

III. S-3 MAINTENANCE PROGRAM DEVELOPEMENT

A. INTRODUCTION

To establish the criteria by which the S-3A's maintenance program was developed, a discussion of the MSG-2 logic and Analytical Maintenance Program follows. The purpose of this discussion will be to identify the differences between MSG-2 and MSG-3 philosophy and how the S-3A might benefit from the RCM program.

B. ANALYTICAL MAINTENANCE PROGRAM (MSG-2)

The Department of Defense contracted with United Airlines in 1972 to apply MSG-2 logic to all Naval aircraft including the S-3A aircraft. In 1978 the MSG-2 logic logic was incorporated into a Naval Air publication 00-25-400 entitled: Analytical Maintenance Program Guide for the Application of Reliability Centered Maintenance for Naval Aircraft (Ref 5). Along with MSG-2 philosophy, many other programs were incorporated into the Analytical Maintenance Program (AMP). These programs included:

a. The Engineering Cognizance Program

b. Analytical Maintenance Program Analysis Support (AMPAS) System

c. Aeronautical Analytical Rework Program (AARP)

d. S-3 Aircraft Advanced Maintenance Program

e. Phased Maintenance Program

f. Hourly Engine Maintenance Program

g. Maintenance Plan Program

The Analytical Maintenance Program was established for essentially the same reason that persuaded the airline industry: to operate a piece of equipment with a certain probability of success at the lowest possible cost over the entire life cycle of operation.

There were three phases to the AMP: Analysis, Implementation and Sustaining. The analysis phase applied the MSG-2 logic to each significant item and identified one of three maintenance categories that provided the best solution. They were hard time, on condition and condition monitoring tasks. A brief discussion of each category follows:

a. Hard-Time (HT) Limit - This established a maximum interval for service life of a particular component due to the inability to ascertain degradation of reliability by on-aircraft inspection, testing or measurement.

b. On-Condition (OC) - To determine the condition of a particular item, repetitive inspections or tests are performed to insure a valid "condition standard".

c. Condition Monitoring (CM) - A maintenance process for items that have no high time limits or on condition maintenance tasks as their primary maintenance process. Condition monitoring relies on analysis of item performance records and involves no hands on scheduled maintenance.

In the implementation phase, maintenance categories and requirements were established and culminated with the actual operating documents. The sustaining phase incorporated data

and analysis provided by the program to revise existing maintenance requirements. Only the analysis phase and the sustaining phase will be discussed to illustrate the MSG-2 criteria under which the S-3 maintenance plan was developed.

C. ANALYSIS PHASE

The main objective of MSG-2 was to establish complete justification for all scheduled maintenance requirements (Ref 5: p.1-2). An initial list of potential significant item candidates for analysis was developed by reviewing maintenance instruction manuals, work unit code (WUC) manuals and aircraft system/components by functional hardware breakdown. MSG-2 identified two types of significant items. The first was a maintenance significant item (MSI) which included all systems, subsystems and components of the aircraft/equipment, but excluded fixed airframe structure and the basic aircraft powerplant. An MSI was the forerunner to the Functionally Significant Item (FSI) described in Chapter II. An MSI was an item judged by the analyst to be important from a failure consequence or failure frequency viewpoint which could possibly benefit from scheduled maintenance (Ref 5: Glossary p. 1). The second was a structurally significant item and was defined as an area of the primary structure which was judged by the analyst to be the most important from a fatigue or corrosion vulnerability standpoint (Ref 5: p.3-21).

Other problem areas having been identified through airframe bulletins, technical directives and 3M data were also considered.

Once all the review was completed, it was the analyst's decision as to which items were to be designiated as maintenance significant items (MSI) or structurally significant items (SSI). This was mostly a subjective evaluation with the analyst reviewing each system and component from a hardware standpoint and assessing its importance to the aircraft integrity.

1. <u>MPA-1 Worksheet (Significant Item Selection)</u>

Once the review of these two critical elements was complete, the candidate MSI's and SSI's were recorded on MPA-1 (maintenance plan analysis) worksheet in preparation for further analysis. Figure 9 (Ref 5:p. A-19) is an example of the MPA-1 worksheet. This is the starting point for subsequent analysis steps/worksheets which result in the final determination of actions required to alleviate potential failures for each MSI/SSI undergoing analysis. Each column of the worksheet was then annotated with the following information.

a. **WUC** - The appropriate work unit code was entered here. The WUC identified, numerically, a specific malfunction. If none existed, TBE (to be established) was entered.

SIGNIFICANT ITEM LIST

MPA 1 sheet 1 of 1

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J E Ervin Code 412D	1 Feb 1978		S 3A Aircraft	NALC 412D

ITEM NOMENCLATURE	PART NUMBER(S)	WUC	EXISTING SCHEDULED MAINTENANCE REQUIREMENTS (BRIEF)	INSP FREQ	PROB SOURCE	DISPOSITION	REF
ARRESTING HOOK SUPPORT	1200302 101 Left Hand	TBE	Zonal Inspection (08.03)	PH (340)	CFA	Delete	MPA 2-3
	1200302 102 Right Hand		Zonal Inspection (08.03, 22.09)	PH (680)	CFA	Delete	MPA 2 3
			Lubricate Pivot Point (08.03)	DS (28)	CFA	No action	MPA 2 4
			Visual Inspection for Evidence of Corrosion (08.03)	DS (56)	CFA	No action	MPA 2 3
			Measure Lug Bushing Inside Diameter for Wear	DLM (20%)		Add	MPA 2 3
			Penetrant Inspection for Cracks in Lug Fillet Area	DLM (20%)		Add	MPA 2 3
			Visual Inspection for Fastener Condition	PH (340)		Add	MPA 2 3

Figure 9. MPA-1 Worksheet

b. Existing/Scheduled Maintenance Requirements - The existing requirements were usually obtained from one of the following publications:

   1. Periodic Maintenance Information Cards
   2. Turnaround Checklists
   3. Daily/Servicing/Special Maintenance Requirement Cards (MRC)
   4. Calendar MRC's
   5. Phased MRC's
   6. Depot Level Maintenance (DLM) Specifications

c. Inspection Frequency - This interval between inspections was determined by engineers without any consideration of the economic consequences of failure. A code such as PREF for preflight, PF for postflight and D for daily were some of the codes utilized.

d. Problem Source - Either CFA (Cognizant Field Authority) or ECA (Equipment Condition Analysis) was entered in this column. If the program was identified through data collected by one of the four ECA reports, ECA was selected. CFA was chosen if the cognizant field authority decided that a problem item, not previously identified through ECA, was a candidate for further analysis.

e. Disposition - This category concerned the final outcome of the decision process. It could only be answered after the remaining worksheets which considered failure modes and effects analysis, scheduled maintenance requirements and performance of maintenance requirements, were complete. Five alternatives were available:

   1. "Retain" the required maintenance process;
   2. "Delete" or change the primary maintenance process from hard-time (HT) to condition monitoring (CM) or on-condition (OC) to (CM);
   3. "Add" a primary maintenance process such as (OC) or (HT);
   4. "Modify" the frequency of maintenance process but maintain the same category. Only the frequency in the (OC) task is changed or the criterion for removal of a (HT) item is altered;
   5. "Problem Item" is defined as an item where a hidden function exists and no valid/effective maintenance requirements are possible; or a failure would have a direct adverse effect on operational safety. Such a disposition would require a redesign to try to eliminate the hidden function by either visible access or additional warning instrumentation.

f. Reference - This column identified the data analysis worksheet that documented that type of disposition.

2. <u>MPA 2-1A (Structure Significant Item Analysis)</u>

For each SSI identified by the analyst, Figure 10 (Ref 5:p. A-20) provided the necessary documentation for the structural analysis. A rating system was applied by the analyst and engineer to obtain a numerical value for structural criticality. Figure 11 (Ref 5:p. A-22) was the analysis rating sheet that was utilized by the Naval Air Rework Facility Alameda, California in determining the criticality of the SSI.

After compiling the data, an overall criticality rating was determined by the analyst and represented the level of structural integrity of the SSI. In most cases, the fatigue or corrosion resistance rating or the lowest rating in any category determined the overall criticality rating (Ref 5 :pp.3-29).

Depending on the criticality rating and the SSI's impact on safety, a structural examination or sampling plan was developed and proposed by the analyst. Figure 12 (Ref 5 :p. A-21) is an example of the structural frequenct/sampling table that was applicable to the S-3. This table provided a basis from which to analyze initial estimates of sample size and frequency requirements.

STRUCTURAL SIGNIFICANT ITEM ANALYSIS — MPA 2-1A

NOMENCLATURE	REV. NO./DATE	WUC	ZONE	PREPARED BY	DATE
ARRESTING HOOK SUPPORT		TBE	04 03 08 03 22 09	J. E. Ervin Code 412D	1 Feb 1978

APPLICATION	PART NUMBER
S-3A Aircraft	Left Hand 1200302-101 Right Hand 1200302-102

CORROSION

RESISTANCE	4
ENVIRONMENT (1)	2
SURFACE TREATMENT (2)	3
ASSEMBLY	4
OVERALL	3

DESIGN DESCRIPTION

a titanium forging (6AL-6V-2SN) annealed comprised of;

1) a lug for arresting hook attachment
2) a flange for attaching and transmitting loads to the 578 bulkhead (BHD)
3) a beam channel acting as the lower cap for the keelson

The BHD and keelson attaching fasteners are HLT 318 and the skin fasteners are AD rivets. LH and RH installations are symmetric about aircraft centerline.

STRESS DATA

Lug M.S. = 0.39
Attach M.S. = 0.52
LR 24601

2

OPERATING HISTORY OR APPLICABLE DATA

No specific info. MEA refers to A-7 experience for arresting gear components.

CRACKING

FATIGUE DATA

31,500 hrs. - Math. Comp.
LR 24614

2

STRESS CORROSION	3
OVERALL	2

REMARKS

(1) For lug the environment is rated 2, for the beam area between FS 551 & 578 the rating is 3

(2) Passivate + 306 prime + 310 paint. Skin attachment is fay sealed.

Figure 10. MPA 2-1A Worksheet

S-3A AIRCRAFT
SSI ANALYSIS RATING SHEET

	POOR 1	FAIR 2	GOOD 3	EXCELLENT
CORROSION				
	RELATIVE CORROSION SUSCEPTIBILITY OF MATERIAL			
SUSCEPTIBILITY	2000 & 7000 SERIES AL	HIGH HEAT TREAT STEEL 6000 AL	NICKEL CRES	TITANIUM
	ITEMS WORKING ENVIRONMENT			
ENVIRONMENT	SEA SPRAY EXHAUST EXTREME TEMP	WEAR ABRASION SALT WATER ATMOSPHERE	AIR COND VARIABLE TEMPERATURE	SEALED FROM ELEMENTS OIL IMMERSION
	ANTI CORROSION TREATMENT			
SURFACE TREATMENT	HARD ANODIZE CHEM FILM	ANODIZE CHROME PLATE CHEM FILM • PRIME PASSIVATE	CAD PLATE ANODIZE • PRIME CHEM FILM • PRIME • PAINT	ANODIZE • PRIME • PAINT CAD • PRIME • PAINT NICKEL PLATE
	SEALANT APPLICATION DURING ASSEMBLY			
ASSEMBLY	DISSIMILAR METAL UNSEALED	UNSEALED SIMILAR METAL	DISSIMILAR METAL SEALED	SEALED SIMILAR METAL
STRESS				
	DESIGN MARGIN OF SAFETY			
STRESS LEVEL	0 00 0 25	0 26 0 50	0 51 1 00	GREATER THAN 1 00
CRACKING				
	FATIGUE RESISTANCE IN TERMS OF ITEM FATIGUE LIFE (HOURS)			
FATIGUE RESISTANCE	26 000 30 000	30 000 50 000	50 000 75 000	GREATER THAN 75 000

Figure 11. S-3A Aircraft SSI Analysis Rating Sheet

S 3A AIRCRAFT
STRUCTURAL SAMPLING TABLE

OVERALL CRACKING OR CORROSION RATING	IMPACTS OP. SAFETY	FLEET (O/I)		DEPOT	
		CORROSION	CRACKING	CORROSION	CRACKING
1	YES	56 DAY	TURNAROUND	DLM	100%
1	NO	56 DAY	170 HR	DLM	100%
2	YES	56 DAY	170 HR	DLM	100%
2	NO	56 DAY	340 HR	DLM (20%)	20%
3	YES	56 DAY	340 HR	DLM (20%)	20%
3	NO	112 DAY	680 HR	DLM 2 (20%)	10%
4	YES	112 DAY	340 HR	DLM 2 (20%)	10%
4	NO	112 DAY	680 HR	DLM 2 (10%)	10%

Figure 12. S-3A Aircraft Structural Sampling Table

3. MPA 2-1 Worksheet (Failure Modes and Effects Analysis)

After MSI/SSI selection was complete, failure mode and effects analysis (FEMA) for each item was performed by completing the MPA 2-1 worksheet, Figure 13 (Ref 5: pp.A-23,24). Failure modes are the specific ways in which an item can fail and were broken down into two types: Functional and engineering failure modes. A funtional failure was defined as the inability of an item to perform its normal or characteristic actions within specified limits. An engineering failure is an actual physical deviation from the design limit (Ref 13:p.5). Identifying each engineering failure mode that could apply to given functional failure is quite important in the analysis process.

The intent of this worksheet was to ensure that only realistic failure modes are analyzed. The analyst could then be fairly confident that a maintenance task was not going to be assigned to a failure mode that would never occur.

4. MPA 2-2 Worksheet (Development of Potentially Effective Scheduled Maintenance Requirements)

Upon completion of the FEMA analysis for each MSI and SSI, MPA 2-2, Figure 14 (Ref 5:p. A-25) was used to recognize all potential maintenance tasks. The decision to accept or reject these tasks was determined in later maintenance plan analysis worksheets. The logic provided by the worksheet helps identify potential tasks that would

FAILURE MODES AND EFFECTS ANALYSIS

MPA 2-1 sheet 1 of 2

ITEM NUMENCLATURE	NO ON ENG/AC	ZONE	PREPARING ACTIVITY	WUC
ARRESTING HOOK SUPPORT	2	04 03 08.03 22.09	NALC 412D	TBE

PART NUMBER	APPLICATION	PREPARED BY	DATE	REV NO	REV DATE
Left Hand 1200302 101 Right Hand 1200302 102	S 3A Aircraft	J. E. Ervin NALC, Code 412D	1 Feb 1978		

ITEM DESIGN DESCRIPTION FUNCTION(S) A titanium forging (6AL 6V 2SN)annealed comprised of a lug for arresting hook attachment, a flange for attaching and transmitting loads to the 578 bulkhead (BHD) and a beam channel acting as the lower cap for the keelson. The BHD and attaching fasteners are HLT 318 and the skin fasteners are AD rivets. Left hand and right hand installations are symmetric about aircraft centerline. The functions are (1)resists bending loads applied to keelson,(2) transmits arresting loads to

REDUNDANCIES PROTECTIVE WARNING DEVICES FAIL SAFE SYSTEMS

NONE

FAILURE MODES	FAILURE EFFECTS
1. Loss of normal arresting capability (a) Lug Fracture.	1. Inability for arrested landing. During carrier operations this would result in orobable loss of aircraft.
2. Loss of resistance by lower cap to lateral loads applied to keelson (a) Web Fracture	2. Skin warp and BHD deformation. Aircraft could be safely recovered after flight.
3 Loss of lower skin/BHD Attachment (a) Fastener Fracture.	3. Loss of structural stability and/or continuity. Possible loss of arresting capability. During carrier operations this would result in probable loss of aircraft.

Figure 13. MPA 2-1 Worksheet

FAILURE MODES AND EFFECTS ANALYSIS

MPA 2 1 sheet 2 of 2

ITEM NOMENCLATURE	NO UN ENG/AC	ZONE	PREPARING ACTIVITY	WUC
ARRESTING HOOK SUPPORT	2	04 03 08 03 22 09	NALC 412D	TBE

PART NUMBER	APPLICATION	PREPARED BY	DATE	REV NO	REV DATE
Left Hand 1200302 101 Right Hand 1200302 102	S 3A Aircraft	J E. Ervin NALC. Code 412D	1 Feb 1978		

ITEM DESIGN DESCRIPTION FUNCTION(S)

578 BHD and keelson, (3) provides pivot for arresting gear and (4) provides keelson attach to skin and BHD.

REDUNDANCIES PROTECTIVE WARNING DEVICES FAIL SAFE SYSTEMS

FAILURE MODES	FAILURE EFFECTS

Figure 13. MPA 2-1 Worsheet (Continued)

DEVELOPMENT OF POTENTIALLY EFFECTIVE SCHEDULED MAINTENANCE REQUIREMENTS

MPA 2-2 sheet 1 of 1

ITEM NOMENCLATURE	PART NUMBER	APPLICATION	WUC
ARRESTING HOOK SUPPORT	Left Hand 1200302-101 Right Hand 1200302-102	S-3A	TBE

a IS IMPENDING FAILURE DETECTABLE BY FLIGHT CREW MONITORING? a1. No a2. No a3. No	IF YES, GIVE FAILURE MODE AND DEFINE MEANS OF MONITORING
b IS IMPENDING FAILURE DETECTABLE BY ON AIRCRAFT MAINTENANCE OR UNIT TEST? b1 Yes b2 Yes b3. Yes	IF YES GIVE FAILURE MODE AND LIST ALL POTENTIAL TASKS THAT WOULD DETECT IMPENDING FAILURE (CHECK, INSPECT, SERVICE, ETC.) b1a. Penetrant inspection for cracks in lug fillet area. b1b. Visual inspection for corrosion, pay particular attention to lug area. b1c. Measure lug bushing inside diameter for wear. b2. Intensive visual for cracks in web area, pay particular attention to fillet radius. b3. Visual inspection for fastener condition.
c DOES FAILURE MODE HAVE A DIRECT ADVERSE EFFECT ON OPERATING SAFETY? c1. Yes c2. No c3. Yes	IF YES GIVE FAILURE MODE AND LIST ALL POTENTIAL TASKS REFERRING TO OPERATING SAFETY (TOTAL TIME LIMITS, CHECK, INSPECT, ETC.) c1a. Penetrant inspection for cracks in lug fillet area. c1b. Visual inspection for corrosion, pay particular attention to lug area. c1c. Measure lug bushing inside diameter for wear. c3. Visual inspection for fastener condition.
d IS THE FUNCTION HIDDEN FROM THE VIEWPOINT OF THE FLIGHT CREW? d1 No d2. No d3. No d4. No	e IS THERE AN ADVERSE RELATIONSHIP BETWEEN AGE AND RELIABILITY? Yes, based on contractor dynamic testing for operationally inducted wear of pivot point with and without lubrication.
IF YES, LIST ALL POTENTIAL TASKS REFERRING TO HIDDEN FUNCTION (CHECK, INSPECT, ETC.)	IF YES, POTENTIAL FOR OC OR HT MAINTENANCE TASK e1. Periodic lubrication of pivot point.

Figure 14. MPA 2-2 Worksheet

detect impending failure. Consideration was also given to the method of failure detection and if the failure had a direct adverse effect on operational safety.

5. MPA 2-3 Worksheet (Definition of Scheduled Maintenance Requirements Which Must be Performed)

Figure 15 (Ref 5: pp.A-26,27) was used to specify those maintenance requirements that were essential in promoting operational safety and reducing the possibility of hidden functional failures. Failures that were identified on the MPA 2-2 worksheet as having a direct adverse effect on safety were analyzed and further defined. Because a hidden functional failure is a failure of a component that is not evident to the operating crew, one of three alternative tasks are available: an on-condition task, a high-time removal, or a redesign of the item to eliminate the hidden characteristics.

To complete this worksheet, contractor design/failure reports, safety center reports, 3M data and in house investigations were utilized to effectively answer the logic sequence. When inspection frequencies were in question, a threshold sampling program was considered. This program was intended to recognize potential failures by "on-condition" inspection of aircraft systems. By repetitive sampling, the program would determine the condition of the component and if possible, justify continued operation until the next sample limit. Sample sizes were determined by

DEFINITION OF SCHEDULED MAINTENANCE REQUIREMENTS WHICH MUST BE PERFORMED

MPA 2-3 sheet 1 of 2

ITEM NOMENCLATURE	PART NUMBER	APPLICATION	WUC
ARRESTING HOOK SUPPORT	Left Hand 1200302-101 Right Hand 1200302-102	S-3A Aircraft	TBE

I WHICH OF THE TASK(S) REFERRING TO OPERATING SAFETY MUST BE DONE? AT LEAST ONE HT OR OC TASK MUST BE DONE. INCLUDE RATIONALE FOR DECISION	DISPOSITION RELATIVE TO UPDATED ANALYSIS
c1a. Penetrant inspection for cracks in lug fillet area. Contractor fatigue testing has indicated a need to check for cracks in this area (refer to attached report #LH 23-14). Inspect at depot at DLM 20% (refer to attached structural sampling table).	Include
c1b. Visual inspection for corrosion in lug area. The lug area is easily accessible and corrosion on similar aircraft (refer to attached UR's) has been a problem. Inspect at organizational level every 65 days (refer to attached structural sampling tables).	Include
c1c. Measure lug bushing inside diameter for wear. In instances involving like aircraft (refer to attached UR's), it was determined that worn lug bushings had contributed to lug fracture. Inspect at depot at DLM 20% (refer to attached structural sampling table).	Include
II A DOES LOSS OF FUNCTION AFFECT CREW SURVIVABILITY, EMERGENCY SYSTEMS, OR ESSENTIAL FLIGHT FUNCTIONS? IF YES CONTINUE WITH QUESTION II B. IF NO CONTINUE ON MPA 2-4 Question d generates "NO" answers for all functions, see MPA 2-2.	
II B WHICH OF THE TASK(S) REFERRING TO HIDDEN FUNCTION(S) MUST BE DONE? AT LEAST ONE HT OR OC TASK MUST BE DONE. INCLUDE RATIONALE FOR DECISION	

Figure 15. MPA 2-3 Worksheet

DEFINITION OF SCHEDULED MAINTENANCE REQUIREMENTS WHICH MUST BE PERFORMED

MPA 2 3 sheet 2 of 2

ITEM NOMENCLATURE	PART NUMBER	APPLICATION	WUC
ARRESTING HOOK SUPPORT	Left Hand 1200302 101 Right Hand 1200302 102	S-3A Aircraft	TBE

I WHICH OF THE TASK(S) REFERRING TO OPERATING SAFETY MUST BE DONE? AT LEAST ONE HT OR OC TASK MUST BE DONE. INCLUDE RATIONALE FOR DECISION	DISPOSITION RELATIVE TO UPDATED ANALYSIS
c3 Visual inspection for fastener condition. In six instances (five [5] on the A-7 aircraft, one [1] on the S 3A) visual inspections have discovered early stages of corrosion and cracks. The visual inspection requires very little time and is easily accomplished. Inspect at organizational level at every 400 flight hours.	
II A DOES LOSS OF FUNCTION AFFECT CREW SURVIVABILITY, EMERGENCY SYSTEMS OR ESSENTIAL FLIGHT FUNCTIONS? IF YES CONTINUE WITH QUESTION II B. IF NO CONTINUE ON MPA 2 4	
II B WHICH OF THE TASK(S) REFERRING TO HIDDEN FUNCTION(S) MUST BE DONE? AT LEAST ONE HT OR OC TASK MUST BE DONE. INCLUDE RATIONALE FOR DECISION	

Figure 15. MPA 2-3 Worksheet (Continued)

inspecting systems as they became available through routine service and actual system failure. Additional inspections were specifically tasked if supplemental information was required to justify maintenance task revision. It was the analyst's responsibility to gather data from existing sources in order to: (Ref 5: p. 3-51)

a. Define the condition of a system at a particular inspection;

b. Consider granting an interval extension or require additional samples to be obtained based on reports of favorable condition at the existing inspection;

c. Recommend design changes if the subsequent inspection indicates negative results. However, economic considerations were carefully reviewed before such a recommendation could occur.

All items that were selected by the analyst as sampling program candidates were then anotated on the MPA 2-3 worksheet with supporting rational. Little guidance was provided as to the criteria by which sample size was determined or program implementation procedures.

6. <u>MPA 2-4 Worksheet (Definition of Scheduled Maintenance Requirements Which Should be Performed)</u>

The fifth worksheet was designed to test and evaluate economic consequences of performing needed maintenance tasks. The purpose of Figure 16 (Ref 5: pp.A-28,29) was to justify, economically, if a maintenance task was warranted for failures that did not effect operational safety.

DEFINITION OF SCHEDULED MAINTENANCE REQUIREMENTS WHICH SHOULD BE PERFORMED

MPA 2-4 sheet 1 of 2

ITEM NOMENCLATURE	PART NUMBER	APPLICATION	WUC
ARRESTING HOOK SUPPORT	Left Hand 1200302 101 Right Hand 1200302 102	S 3A Aircraft	TBE

A DOES REAL AND APPLICABLE DATA SHOW THE DESIRABILITY OF A SCHEDULED TASK?	DISPOSITION RELATIVE TO UPDATED ANALYSIS
IF YES LIST TASKS DATA DESCRIPTIONS LOGIC RATIONALE SKIP QUESTION B IF NO INCLUDE RATIONALE FOR DECISION AND GO TO QUESTION B	
b1a Yes Evaluated and accepted on MPA 2 3, task c1a	Include
b1b Yes Evaluated and accepted on MPA 2 3, task c1b	Include
b1c Yes Evaluated and accepted on MPA 2 3 task c1c.	Include
b2 No Web fracture is tolerable does not affect flight safety The visual examintion generated by task c3 on MPA 2 3 is adequate to detect web failure The task to conduct a visual inspection for fastener condition is therefore not economically justified.	Go to Question B
b3 Yes Evaluated and accepted on MPA 2 3, task c3	
B DOES FAILURE OF ITEM CAUSE MISSION ABORT?	
IF YES EVALUATE TASK AND INCLUDE RATIONALE FOR DECISION IF NO OMIT	
b2. Yes Even though web fracture does not affect flight safety the failure may result in skin warp and BHD deformation If this condition were discovered prior to flight it would possibly result in a mission abort However since task c3 will also detect web fracture, this task b2 is still not economically justified.	Omit

Figure 16. MPA 2-4 Worksheet

DEFINITION OF SCHEDULED MAINTENANCE REQUIREMENTS WHICH SHOULD BE PERFORMED

MPA 2-4 sheet 2 of 2

ITEM NOMENCLATURE	PART NUMBER	APPLICATION	WUC
ARRESTING HOOK	Left Hand 1200302 101 Right Hand 1200302 102	S 3A Aircraft	TBE

A DOES REAL AND APPLICABLE DATA SHOW THE DESIRABILITY OF A SCHEDULED TASK?	DISPOSITION RELATIVE TO UPDATED ANALYSIS
IF YES LIST TASKS DATA DESCRIPTIONS LOGIC RATIONALE SKIP QUESTION B IF NO INCLUDE RATIONALE FOR DECISION AND GO TO QUESTION B e1 Yes - Data on a similar aircraft (A 7) has indicated a need to lubricate pivot point This task is also justified by contractor dynamic testing for operationally inducted wear of the pivot point. (Refer to attached manufacturer's report #LH 235 16.) Lubricate every 30 days at organizational level.	Include
B DOES FAILURE OF ITEM CAUSE MISSION ABORT?	
IF YES EVALUATE TASK AND INCLUDE RATIONALE FOR DECISION IF NO OMIT	

Figure 16. MPA 2-4 Worksheet (Continued)

7. MPA 2-5 Worksheet (Scheduled Maintenance Requirements Data Sheet

The final worksheet, Figure 17 (Ref 5:p.A-32) provided the data for each scheduled maintenance action that was determined to be necessary and cost beneficial. Each maintenance action was then categorized into particular areas or zones that would benefit the inspection process. By dividing the aircraft into inspection zones, the most efficient schedule was implemented to coordinate all maintenance actions that pertained to that particular zone. The analyst, along with engineering experts, determined the following by zones : (Ref 5: p.3-53)

a. Phase cycle structure and phase intervals;

b. Depot Level Maintenance (DLM) intervals;

c. Which on-condition and high time requirements could be grouped into either the phase inspection package or the DLM inspection process.

These final requirements became part of the overall maintenance plan and were incorporated into Part III of NAVAIRINST 4790.4 (Ref 14). A sample of the maintenance requirements are provided in Figure 18 (Ref 5: pp.A-30,31). Note that each requirement number corresponded directly to a specific maintenance requirement that was generated by the AMP analysis.

Part III of the Maintenance Plan and the MPA 2-5 worksheet provided the information necessary for the development of the organizational, intermediate and depot level maintenance publications.

SCHEDULED MAINTENANCE REQUIREMENTS DATA SHEET

MPA 2 5 sheet 1 of 1

NOMENCLATURE DESIGNATION	PREPARED BY	DATE	APPLICATION	WUC
ARRESTING HOOK SUPPORT	J. E. Ervin, Code 412D	1 Feb 78	S-3A	TBE
PART NUMBER Left Hand 1200302 101 Right Hand 1200302-102	PREPARING ACTIVITY NALC 412D		REVISION	REVISION DATE

REQMT #	ZONE	TASK TIME	RATE TRADE CODE	ASSIST REQUIREMENTS	PWR & AIR REQUIREMENTS HYD	CONDITIONED AIR	ELECT	ACCESS REQUIREMENTS	O A	F C F	WARNINGS/ CAUTIONS AND NOTES	CONSUMABLES REPLACEMENT PARTS
1	08.03	1.0	NARF NDI TECH	NONE	NO	NO	NO	Remove arresting gear	YES	NO		
2	08.03	0.3	AMS	NONE	YES	NO	YES	Power hook	NO	NO	Alert personnel before lowering hook.	
3	08.03	1.0	NARF TECH	NONE	NO	NO	NO	Remove arresting gear	YES	NO		
4	04.03 08.03 22.09	1.0	AMS	NONE	NO	NO	NO	Remove panels 6212-1, -2 and 6223-1	NO	NO		
5	08.03	0.2	AMS	NONE	YES	NO	NO	Power hook	NO	NO	Alert personnel before lowering hook.	MIL-G 23827 Grease

Figure 17. MPA 2-5 Worksheet

MAINTENANCE PLAN
PART III - MAINTENANCE REQUIREMENTS

NOMENCLATURE DESIGNATION	PREPARED BY	DATE	APPLICATION	WUC
ARRESTING HOOK SUPPORT	J. E. Ervin Code 412D	1 Feb 1978	S 3A	TBE

PART NUMBER	PREPARING ACTIVITY	REVISION	REVISION DATE
Left Hand 1200302 101 Right Hand 1200302 102	NALC 412D		

REQUIREMENT NO	REQUIREMENT	MAINTENANCE LEVEL	INTERVAL	GROUND SUPPORT EQUIPMENT REQUIRED
1. (b1a, c1a)	Penetrant lug fillet area for cracks (08.03)	DEPOT	DLM (20% Sample)	Dye penetrant kit
2 (b1b, c1b)	Visual inspection for evidence of corrosion (08.03)	ORGANIZATIONAL	DS (56 day)	Flashlight & 10 x glass
3. (b1c, c1c)	Measure lug bushing inside diameter for wear (08.03)	DEPOT	DLM (20% Sample)	Hole Gauge

APPROVED BY	DATE
L. R. Cunningham NAVAIR (Code 4114C3)	10 February 1978

Figure 18. Maintenance Plan Worksheet

D. ANALYTICAL MAINTENANCE PROGRAM SUSTAINING PHASE

The purpose of the analytical maintenance sustaining phase was to review and update established maintenance requirements to ensure maximum operational availability and economic efficiency. The sustaining phase commenced after the maintenance requirements were initially developed and continued until the aircraft was retired from service. The intent of this phase was to refine and continually review maintenance tasks that were initially developed without sufficient statistical or failure information. Without some form of review of these borderline maintenance tasks, an efficient maintenance program could not exist. Although no particular program was detailed by the AMP, a general outline of the process was included. It divided the sustaining phase into three major areas:

a. Monitoring

b. Evaluation

c. Update

Monitoring consisted of first gathering data from all available resources such as 3M data, sampling programs, safety center reports, and contractors and engineering investigations. The next step was to determine what of this data was the most applicable and would provide meaningful input into the evaluation process. Once the screened data indicated a possible candidate for further re-evaluation, tracking of the item through various methods provided the basis for the evaluation phase.

The evaluation process analyzed the specific problem and identified the major causes. The analyst then decided on whether or not analytical maintenance program logic should be applied and what type of corrective action could rectify this situation. Again, the economic aspects were considered in deciding if the corrective action should be implemented. After determining which actions were justified, newly generated AMP analysis worksheets were originated.

The updating process consisted of implementing those corrective actions that were the result of the evaluation process. If changes were required to the scheduled maintenance program, close liaison with cognizant field authorities (CFA), supply centers, training facilities and Naval Air Systems Command was required to ensure the changes were implemented in a timely manner.

E. MAJOR DEFICIENCIES IN MSG 2 PHILOSOPHY

Although MSG-2 provided a logical process for analyzing a particular item in terms of its significance to an overall system, many areas in the analysis process lacked specific guidance. Since the S-3's maintenance plan was developed under the MSG-2 philosophy, it is important to note these weaknesses that MSG-3 improved.

a. The significant item selection process was not well defined and could possibly allow identification of an item that had no significance to the system.

b. Once the failure mode and effects analysis determined each functional failure, no logic was provided to relate the failure with the task that was most applicable in ensuring that the failure did not occur.

c. There was no program available to evaluate maintenance tasks that were established with insufficient data. It was left up to the analyst to establish procedures that would enable the task to be re-evaluated using subsequent historical data.

Many areas of the S-3A's maintenance plan would benefit from performing a thorough RCM analysis. However, the cost of such an enormous undertaking would be hard to justify considering the aircraft's age and current economic funding constraints. The alternative should be a partial analysis that would incorporate existing NARF programs with the current philosophies of Reliability Centered Maintenance. Two areas that would benefit the most from RCM are SSI re-evaluation and problem items that have exhibited a higher than normal failure rate. The next chapter will discuss the deficiencies of MSG-2 in detail and how RCM can provide added emphasis to the existing S-3A Analytical Maintenance Program.

IV. IMPROVEMENTS FOR THE S-3A MAINTENANCE PROGRAM

A. RELIABILITY CENTERED MAINTENANCE

Reliability Centered Maintenance is the refined product of MSG-2 and provides detailed methodology in determining scheduled maintenance requirements, inspection interval determination, and age exploration candidates. The logic and analytical techniques furnished by RCM philosophy, enable the analyst to formulate consistent and well defined results. As stated previously, RCM is designed to provide a disciplined logic or methodology for identifying preventive maintenance tasks that will realize the inherent reliability of equipment at least expenditure of resources. To accomplish this goal, specific maintenance tasks are identified for each functional failure and, through an effective age exploration program, operational data is gathered to insure that a safe and reliable maintenance program is developed.

As stated in the preceding chapter, one of the programs that would benefit the most from integrating RCM analytical techniques is in examining structurally significant items. NARF Alameda is currently examining its structurally significant items for the S-3A utilizing a program developed under the Naval Air System Command's Analytical Maintenance Program (AMP). Called the Structural Sampling Program

(SSP), it incorporates MSG-2 philosophy and its purpose is to perform the minimum number of examinations necessary to assess a change in the material condition of a structurally significant item. It has as its basis some of the same analytical design characteristics that were eventually contained in the Age Exploration Program. The data generated by the SSP is intended to monitor changes in the material condition of the SSI, update the maintenance plan, and identify SSI's that need further analysis (Ref 15:p. 1). Although the SSP has the potential to become an integral part of the overall maintenance effort, many areas of this program could benefit from incorporating RCM philosophy and refined age exploration techniques.

Items not classified as SSI's but are exhibiting an excessive failure rate would also benefit from RCM analysis. These items need a thorough investigation to identify the proper maintenance tasks for reducing the failure rate.

The areas that will be discussed will emphasize how RCM can benefit the existing SDLM programs of the S-3A. They include:

a. Significant Item Selection and Tracking Methodology,

b. Failure Mode and Effects Analysis and Maintenance Task Selection and Determination,

c. Age Exploration Program.

MIL-STD-2173 (AS) (Ref 7) provides procedures and techniques for applying RCM logic to Naval aircraft, weapon

systems and support equipment. New revised worksheets have been developed that analyze each maintenace task category for applicability and effectiveness. Because each worksheet is discussed in great detail in MIL-STD-2173, it will not be individually analyzed here. Only the particular elements that MSG-3 clarified and re-defined will be discussed to demonstrate the importance of applying the logic to the S-3A Structural Sampling Program and problem item analysis.

B. SIGNIFICANT ITEM SELECTION AND TRACKING METHODOLOGY

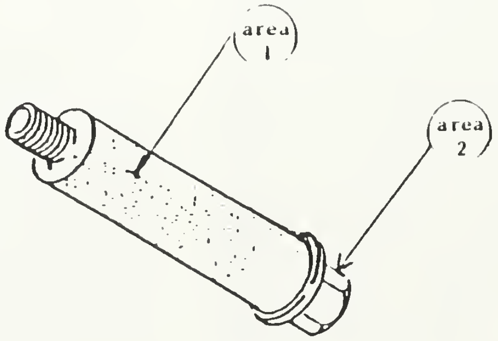
The significant item selection process was discussed in detail in Chapters II and III. It is important to note that no decision logic was provided in MSG-2 to assist the analyst in determining if the item should be classified as structurally significant, functionally significant or categorized as non-significant. Since the SSP was developed utilizing MSG-2 logic, it is possible that elements could be classified incorrectly or worse, not classified at all.

Since the SSI's that the Structural Sampling Program examined were not identified using the logic provided by RCM, it is important that each SSI that the Structural Sampling Program looks at be verified as being truly significant to the system. If not, a great deal of wasted resources will be expended on a task that is not really necessary.

The SSP is designed to sample, on a continuing basis, each SSI. A thorough cross section of statistical data is derived by utilizing a matrix provided by SSP that determines sample size and inspection frequencies. The analytical process of determining sample size and inspection frequency is similar to that detailed in the Age Exploration Program. To determine which SSI is to be looked at, the SSP matrix first identifies the aircraft by bureau number (BUNO), determines which standard depot level maintenance (SDLM) visit the aircraft is scheduled for and finally which work package must be performed. Each work package contains certain SSI's that must be looked at and requires the results to be annotated on the SSI worksheet Figure 19 (Ref 15). These worksheets are then gathered by the analyst for further evaluation. However, no method has been derived to track or analyze the data collected for each SSI. To assist the analyst in this endeavor, a work sheet, Figure 20, is provided that will consolidate information pertaining to each SSI.

By tracking each SSI separately, trends can be readily identified and appropriate RCM analysis can be initiated. Not only failure data needs to be collected, SSI's with no failures also need to be tracked. Part I of the worksheet can be used to effectively track SSI data.

ITEM NO ENCLATURE	LINE NUMBER	WUC	PART NUMBER	
R/H NLG BOLT, SHOCK ABSORBER TO FS 415 BULKHEAD	06.01.09		1285129-101, -103	
	BUNO	SEQUENCE NO	DLM NO	FLT HRS
INSPECTION REQUIREMENTS *				



	MAL CODE	AREA(S)
CORROSION	170	
CRACKED	190	
WORN, STRIPPED	020	
BROKEN	070	
BENT, BUCKELED	780	
FAILED TEST	570-576	
OTHER		
NO DEFECT	799	

REMARKS

STAMP

CORROSION REPORTING**		
INSPECTION AREA	TYPE CODE	SEVERITY CODE

NDI REPORTING	
NDI INSPECTION METHOD	STAMP NO

SPECIFICATION TOLERANCES			
DIAMETER NO	WEAR LIMIT	ACTUAL	STAMP NO

Figure 19. SSI Worksheet

Not all SSI failures will be detected during the scheduled SDLM inspection. Failures that occur operationally will be annotated in Part II of the worksheet. This will provide a ready reference as to which aircraft experienced the failure, who initiated the report, the date of the report and the exact nature of the failure. This format can be used to track such reports as Engineering Investigations (EI), safety reports and other maintenance related messages. The analyst can also adopt this worksheet to track items that are not identified as significant items but are experiencing an excessive failure rate.

This tracking of SSP and problem item data is extremely important for the preventive maintenance program to be effective. Once the significant items are identified and trends develop that indicate a problem, RCM can provide an effective means by which to analyze the component. A full scale RCM analysis can be performed to verify if the task is warranted, identify if an inspection interval adjustment is required, or further data is required for a decision and age exploration is warranted. The important point is, however, that the analyst must first be able to identify which items require further analysis. The data that is currently being collected for the SSP program is not broken down by specific SSI. Rather, it has been categorized by which aircraft the SSI failure occurred on. By tracking each SSI and problem

item separately, these items will be identified and the analyst will have a documented trail from which to base his RCM analysis.

SSI TRACKING WORKSHEET

SSI LINE NUMBER	ITEM NOMENCLATURE	WUC	PART NUMBER

PERCENT OF AIRCRAFT SAMPLED

PART I - FAILURES IDENTIFIED THROUGH NORMAL SDLM VISIT

A/C BUNO	DATE	SDLM	TYPE OF FAILURE (IF NONE, SPECIFY)	NOTES
1.				
2.				
3.				

PART II - FAILURES IDENTIFIED THROUGH OTHER SOURCES

A/C BUNO	DATE	SOURCE OF INFO	ORIGINATOR (MESSAGE DTG)	TYPE OF FAILURE
1.				
2.				
3.				

Figure 20. Tracking Analysis Worksheet

C. FAILURE MODES AND EFFECTS ANALYSIS AND MAINTENANCE TASK SELECTION AND DETERMINATION

Failure Modes and Effects Analysis (FMEA), under MSG-2 guidelines, was intended to isolate each legitimate functional failure mode and in turn, identify the related causes. Once these failure modes and effects were

determined, a maintenance category was selected by the analyst and engineer that was most appropriate. However, no clear logical process was provided utilizing MSG-2 guidelines.

MIL-STD-2173 (Ref 7) and MIL-STD-1629(A) (Ref 10) provide clarification and guidance in performing a thorough FMEA and task evaluation. The FMEA analysis identifies the:

a. Equipment Item,

b. Item's functions,

c. Item's functional failures,

d. Engineering failure modes, and

e. Effects of the failures on the system.

Problem items and SSI's that are identified through the SSP program would require a thorough Failure Modes and Effects Analysis (FMEA) as part of the RCM evaluation. Preventive maintenance analysis is then used to determine if there is some maintenance task which will reduce or prevent the failures identified from the FMEA. In the past, it was a judgemental call by the analyst as to which maintenance category was the most appropriate.

For problem items not defined as an SSI, RCM decision logic details the process to determine the consequences of failure for each failure mode and, depending on the consequence of failure, identifies a particular maintenance task that would best avoid the failure mode. Instead of three maintenance task categories that were originally

identified by MSG-2, RCM identified five separate alternatives. They were defined in Chapter II and are as follows:

a. Servicing lubrication

b. On-condition

c. Hard-time

d. Combination

e. Failure finding

For SSI's that have experienced a well defined trend, either excessive failures or minimal failures, a FMEA is performed as part of the RCM re-evaluation process. The logic will then identify the SSI as either damage tolerant or safe life. Once determined, the decision logic recommends one of the following alternatives:

a. What task is most applicable;

b. Possible age exploration candidate;

c. Redesign;

d. Reconsider if the item is actually a structurally significant item.

After each task is determined, it must be evaluated for applicability and effectiveness. MSG-2 discussed the importance of determining if the task was both applicable and effective, but failed to establish a methodology that would provide acceptable probability of failure levels and cost effectiveness constraints.

RCM logic provides a methodology for determining the effectiveness of a maintenance task. This logic is beneficial in determining if a maintenance task that has been developed for a problem item or SSI is an effective deterent in preventing the items failure. Without performing this analysis, a task could be ineffective as well as uneconomical to perform. The failure consequence determines what type of analysis is applied to the task. Effectiveness criteria is established for safety and safety hidden failure consequences and seperate criterion is developed for economic/operational and non-safety hidden failure consequences.

The RCM decision logic that is provided offers the analyst a clear path from which to base critical decisions that will eventually determine if the task is justified or not. By applying this logic to the Structural Sampling Program and items identified as problem candidates, the analyst can determine the appropriate course of action that had previously been undefined.

D. VERIFICATION OF MAINTENANCE TASKS THROUGH AGE EXPLORATION

In MSG-2, the sustaining phase of the Analytical Maintenance Program (AMP) was designed to provide monitoring, evaluation and updates of assigned maintenance tasks. It recommended using data gathered from such sources as 3M, safety center reports, and contractor's engineering

investigations. However, it failed to provide any specific procedure for analyzing the data. It also failed to detail steps for establishing an effective evaluation program. This is exactly the situation that NARF Alameda finds its SSP program in. Although data is being gathered on SSI's and other problem items, they have not established any real program that analyzes the data.

By integrating RCM and the Age Exploration Program with current NARF analytical programs, the maintenance program can be continually reviewed and updated by gathering data throughout the system's life cycle. The data gathered from an effective age exploration analysis will either verify the validity of an existing maintenance task, identify the need for interval inspection adjustment or determine that additional age exploration analysis is warranted. The methodology provided by the Age Exploration Program would be most beneficial in filling the current void in the Structural Sampling Program and problem item analysis.

The Naval Aviation Logistics Center has recently developed a management manual (Ref 11) that details the requirements for establishing a successful Age Exploration Program in accordance with MIL-STD-2173 (AS) (Ref 7). The methodology provides specific guidance for sample size determination, sampling interval development and suggests techniques to be used for analyzing data collected.

Chapter II stated that all items that use default logic in task evaluation are an age exploration candidate. Other items can also be candidates for age exploration. The Age Exploration Program, (Ref 11:p.26) identifies these as:

a. Items that have been identified as exhibiting poor reliability, high maintenance costs, low availability rates or high abort rates.

b. New items that have been added as a result of modifications or engineering change proposals. However, before an age exploration task is identified, the item must first undergo RCM analysis.

c. Items that cause a significant safety hazard.

It is quite clear that this program would be well suited to fill the void that is hindering the re-evaluation efforts of maintenance task analysis. By defining such an age exploration task and monitoring the failure data, specific knowledge is obtained that will substantiate the need for maintenance program adjustment.

Although it would be extremely beneficial to perform an age exploration analysis on every potential candidate, the economical consequences must be carefully considered. Figure 21 (Ref 11: p.30) illustrates the decision process in determining if an age exploration task is warranted. It also aids in prioritizing the proposed candidates. By following the logic, the candidates that are safety critical and most cost effective are analyzed first. Lower priority candidates are analyzed only if time and money permit.

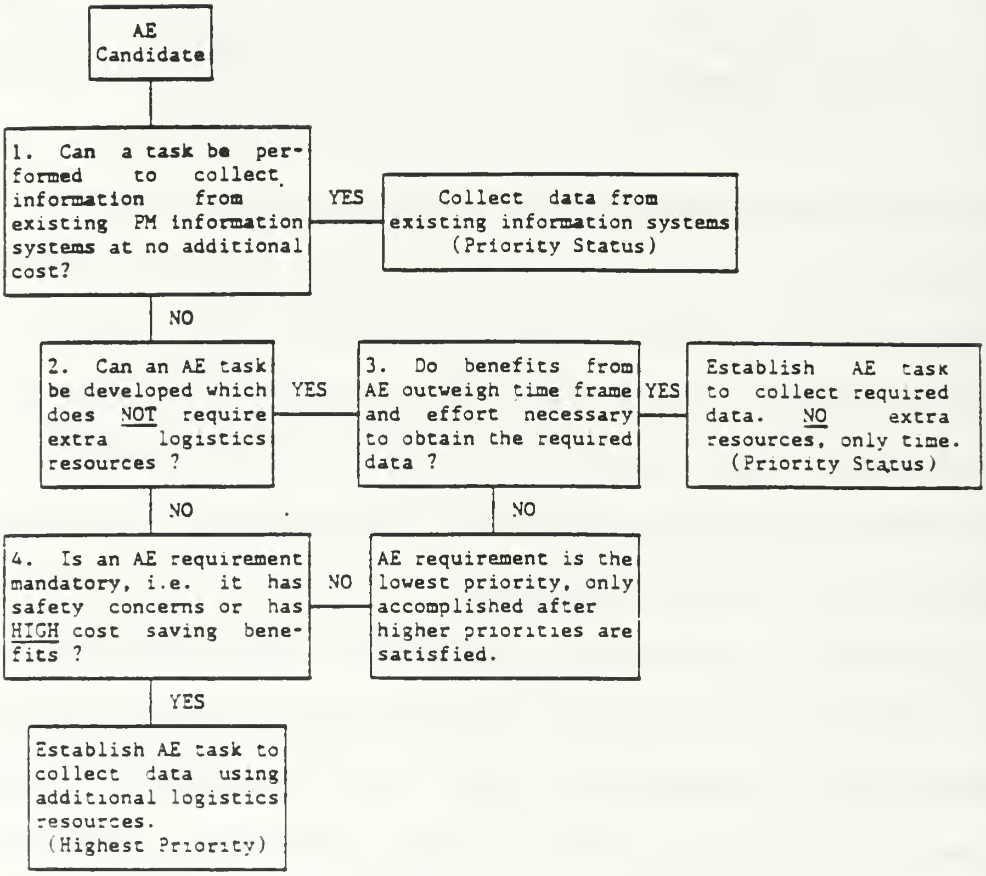


Figure 21. Age Exploration Candidate Task Analysis

After it is determined which candidates would benefit the most from an age exploration analysis, a preliminary task for each candidate must be developed. The task that will be developed must be able to determine specific age relationships by providing an analytical process by which to monitor failure data. In most cases, age exploration is directed at the failure modes of the components and not at the overall system. The analyst, when designing the task, must determine what information is required, how it is going to be obtained, where it can be obtained, who is going to obtain it, and what techniques are to be used to analyze the data (Ref 11:p. 34).

The final output of the age exploration process is to apply the results of the analysis to the preventive maintenance program. This involves inputing this information back into the RCM worksheets to determine the most appropriate maintenance task and inspection interval. RCM, by utilizing the outputs of age exploration, is able to adjust maintenance intervals, adjust maintenance tasks, or modify the design.

E. SUMMARY

Although the basis of the Structural Sampling Program is somewhat related to the Age Exploration Program, the SSP fails to incorporate the required methodology that would enable the analyst to realize the full potential of the

AE program. It must be realized that RCM in conjunction with Age Exploration can play a major role in ensuring that an effective preventive maintenance program is established for SSI's as well as problem items. By not applying some form of re-evaluation process, all the program produces is data. By evaluating each maintenance task and applying the logic of RCM, an effective maintenance concept is achieved that can be adjusted as data is gathered through out the life cycle of the aircraft.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY AND CONCLUSIONS

The intent of this thesis was to demonstrate how Reliability Centered Maintenance could enhance and provide further direction to the existing preventive maintenance program of the S-3A aircraft. It described in detail the Analytical Maintenance Program that was the basis for the current S-3A's maintenance plan. By examining how the maintenance plan was derived, deficiencies were identified in task development and re-evaluation. Removal of these deficiences by the use of RCM allows the analyst to concentrate on preventive maintenance tasks that will increase the inherent reliability of the equipment with the least expediture of resources.

Significant item selection was not well defined utilizing MSG-2 philosophy. RCM clarifies significant item selection and, if the logic does not provide a definitive answer, default logic is provided to assist the analyst in SSI selection decisions. All components that are subject to default logic became age exploration candidates. Age exploration verifies, through data collection and analysis, if the maintenance task for the SSI are valid or require inspection interval adjustment.

Failure Modes and Effects Analysis provides a clear path in analyzing each functional failure and determining which preventive maintenance task would reduce or prevent the identified failure. Dependent on the failure consequence, RCM recommends one of five maintenance tasks categories. After each functional failure has an assigned maintenance task, the task can be evaluated for applicability and effectiveness. Economic as well as safety considerations can be assessed to determine the necessity of establishing a required maintenance task.

Age Exploration is one of the most important elements of the RCM program. By establishing an effective age exploration program, the maintenance program is continually reviewed by gathering historical data throughout the life cycle of the aircraft. Specific knowledge is then obtained that will indicate if a maintenance task adjustment is warranted.

B. RECOMMENDATIONS

The Naval Air Rework Facility at NAS Alameda could benefit substantially by incorporating RCM analysis into existing S-3A preventive maintenance programs. However, performing a thorough RCM analysis on every S-3A component and program can not be justified. It is therefore recommended that RCM be applied selectively to those components and programs that would benefit the most.

The Structural Sampling Program and components that are experiencing excessive failures are two aspects of the maintenance analysis effort that would profit from incorporating RCM analysis. NARF Alameda is currently sampling every structrually significant item through the Structural Sampling Program, but has not established a program by which to analyze the data. Likewise, problem items that are identified "in-house" or through operational channels have not undergone RCM analysis. Thus, the following recommendations are provided:

1. SSP must identify through SSI data collection techniques those items that are experiencing a trend. Both excessive failures and minimal failures must be identified.

2. Problem items that are not SSI's, but are experiencing excessive failures also need to be tracked.

3. Once a trend is identified by the analyst, RCM techniques must be applied to develop a task that will rectify the problem. Possible consequences will include re-defining the task involved, task interval adjustment, or performing further anlaysis through age exploration.

It is most important, that the analyst realize the benefits that RCM can provide. Reliability Centered Maintenance clarifies and broadens the scope of maintenance task analysis and will add significant improvements to existing SDLM Analytical Maintenance Programs.

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